Distant Halo Wide Binaries from SDSS

Universidad de los Andes

ADeLA 2016 @ BOG

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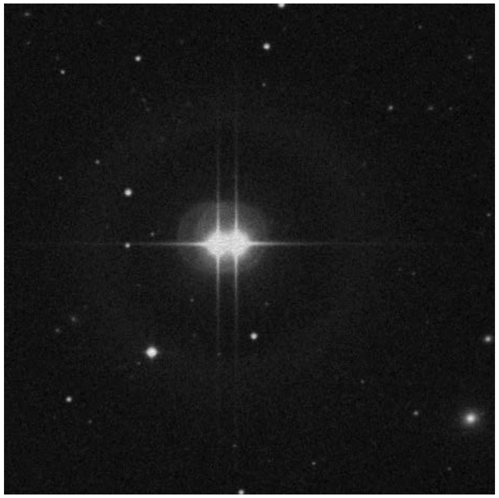
Bogotá, Septiembre 2016

Wide Binaries

$\mu_1 \approx \mu_2$

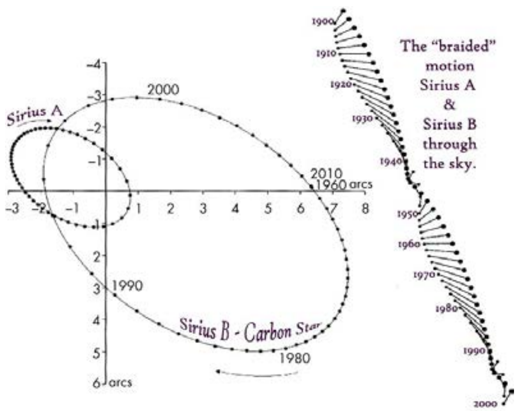
1950

a > 100 AU



2000

Wide Binaries: the non-violent end of the semi-major axis distribution

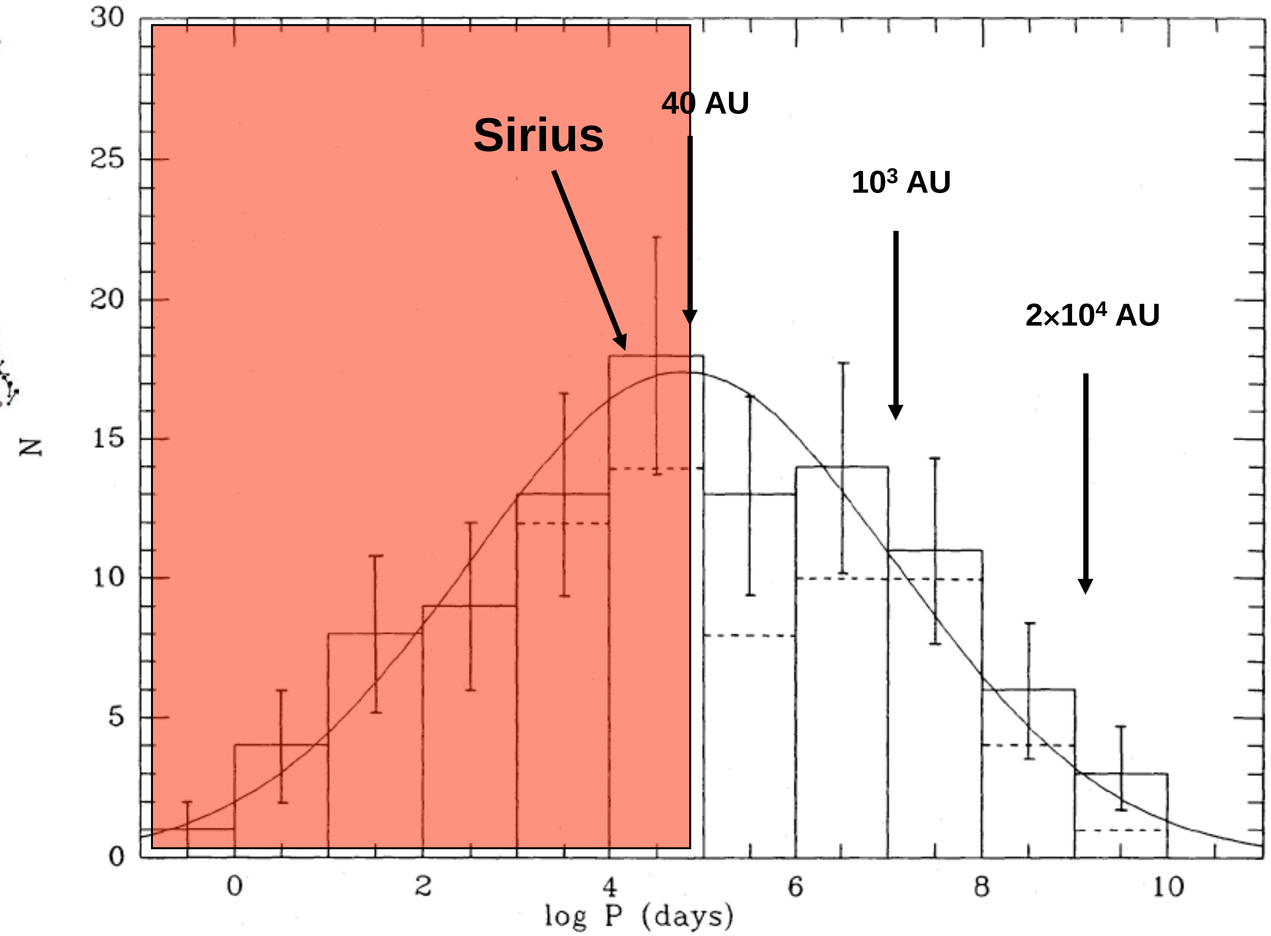


wide binaries

a = 2000 AU
P ~ 10^5 yr

$m = 2\ M_\odot$

$v_{orb} \approx 1$ km/s

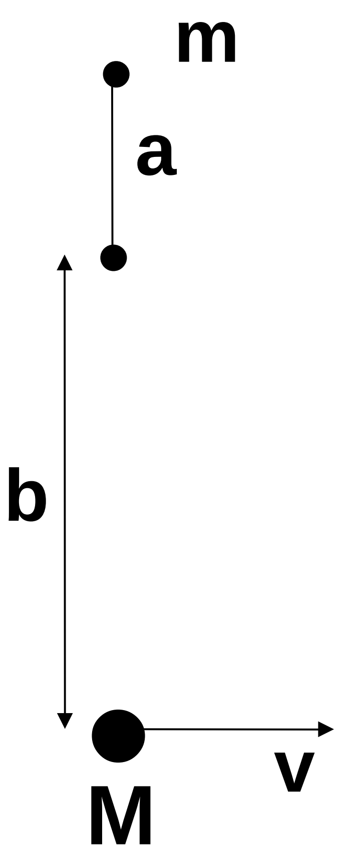


Duquennoy & Mayor (1991)

Wide binaries as dynamical probes

binding energy $\equiv E = -\dfrac{Gm}{2a}$

$a \rightarrow \infty, \quad E \rightarrow 0$



1) b >> a $\Rightarrow$ $|\Delta \mathbf{v}_1 - \Delta \mathbf{v}_2| \equiv \Delta v \simeq \dfrac{2GM}{b^2 v} a.$

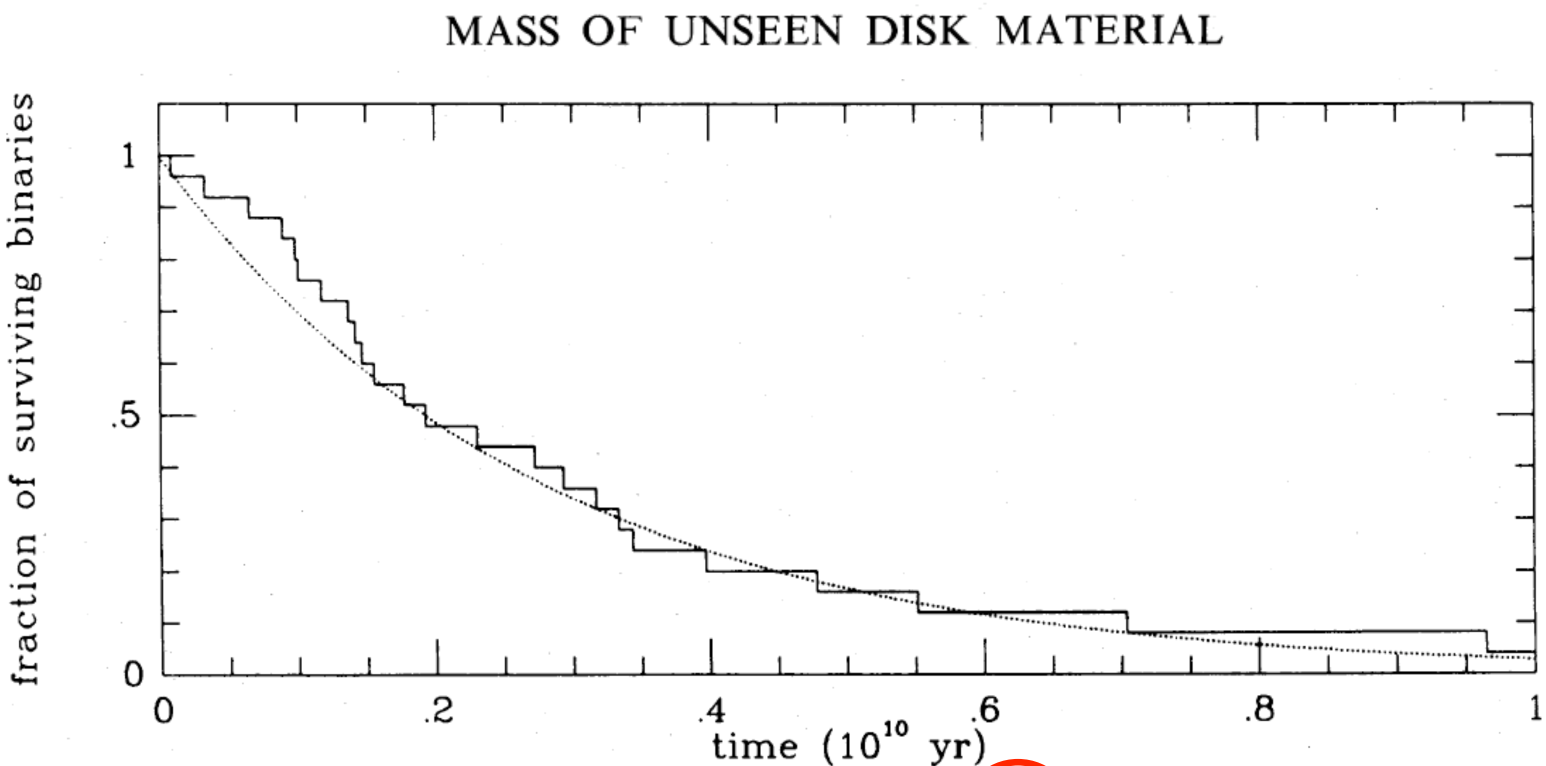
2) condition for destruction: $(\Delta v_{12})^2 \sim \dfrac{G\,m}{a}$

3) closest encounter: $b_{\min} = \left(\dfrac{M}{\pi \rho v T} \right)^{1/2}$

4) ¡ $a \sim \left(\dfrac{4\pi^2 G \rho^2 T^2}{m} \right)^{-1/3} \sim 0.1\,\mathrm{pc}$!

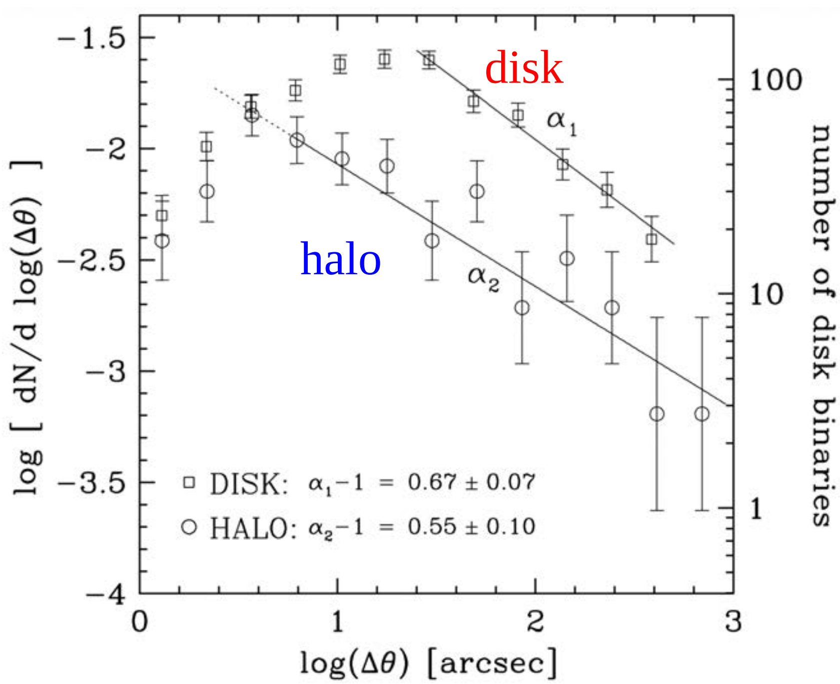
1985: constraints on the nature of (disk) dark matter

Bahcall, Hut, & Tremaine (1985) → $M_{DT} < 2\ M_\odot$



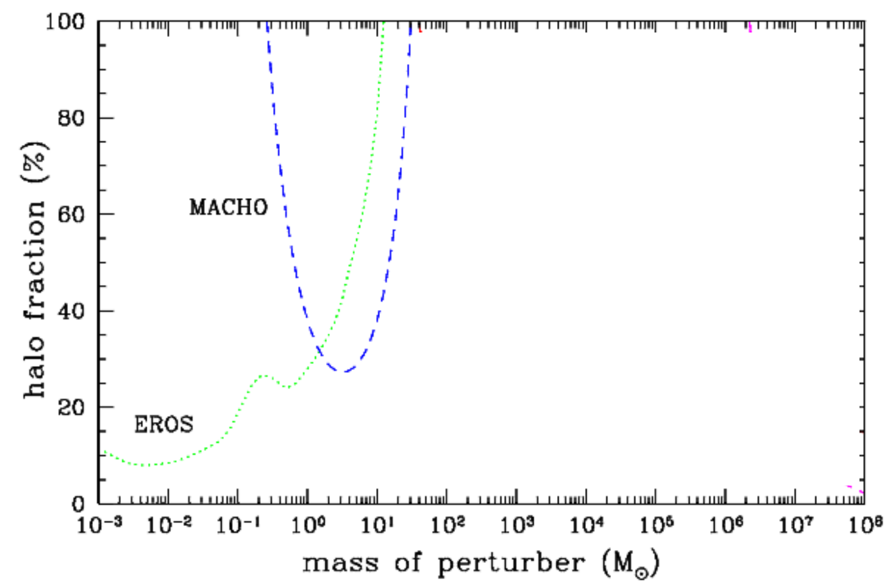
ısemble of 25 binaries, starting at $a = 0.1$ pc, in a sea of DTs with $M_{DT} = 3\ M_\odot$. The dotted line is an ex
)^{10} yr. Note the initial excess of survivors which reflects the diffusive aspect of the dissolution process.

Constraining Halo Dark Matter



JC & Gould (2004)

Yoo, JC, & Gould (2004)



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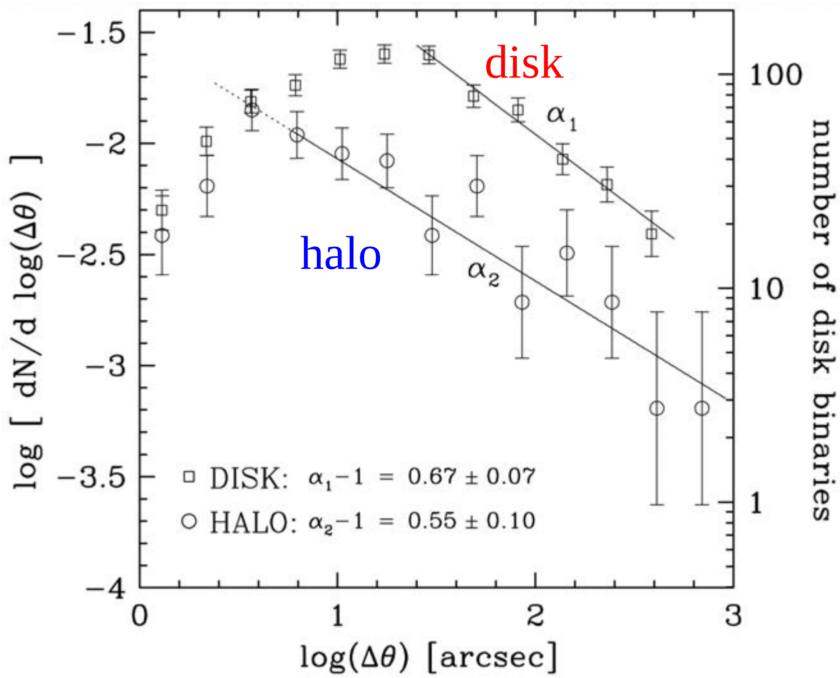

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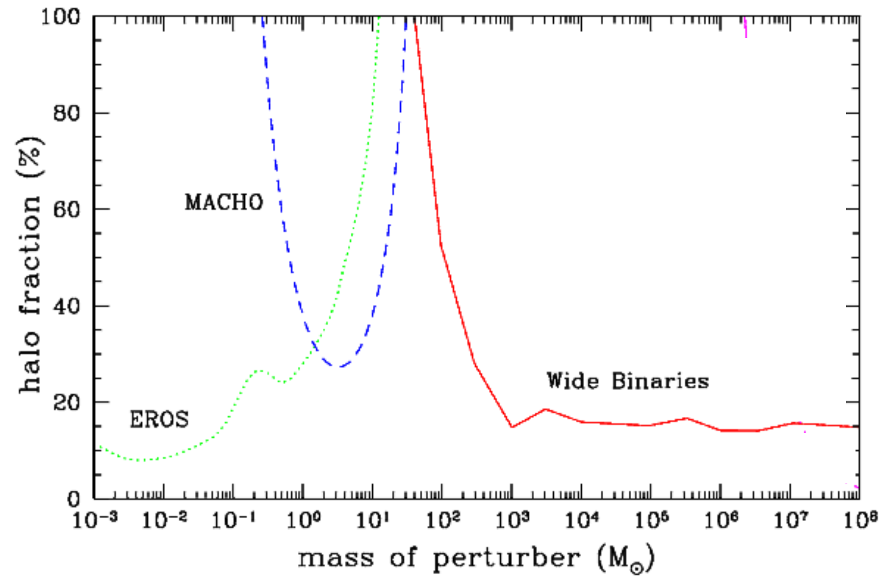

Halo wide binaries exclude MACHOs with $M > 43\ M_\odot$ at the standard local halo density ρ_H at the 95% confidence level (2σ)

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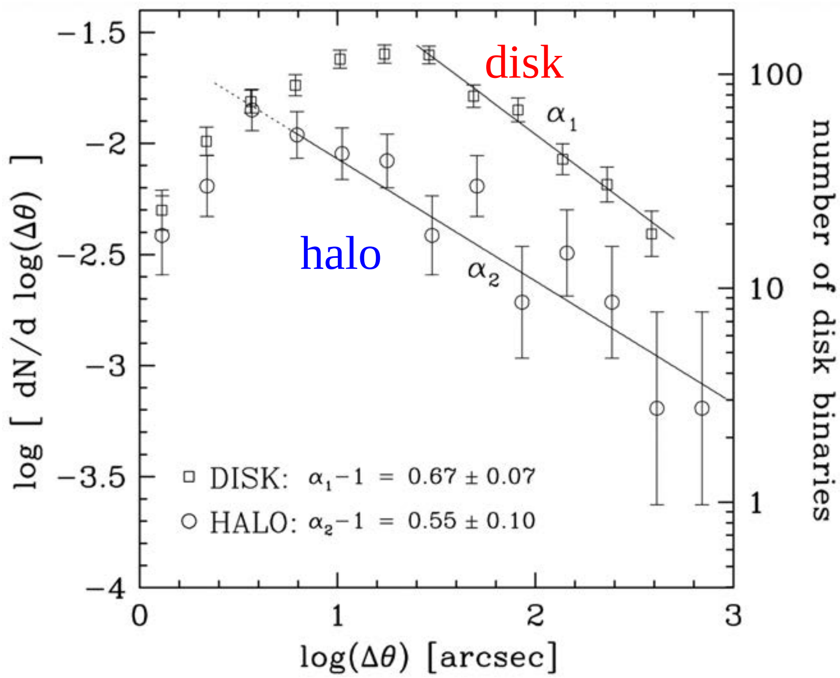

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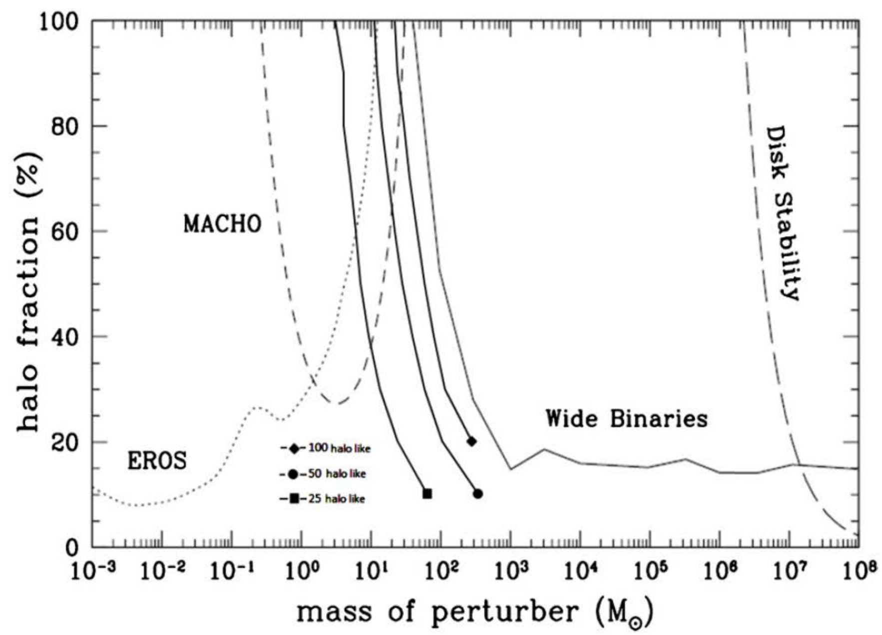

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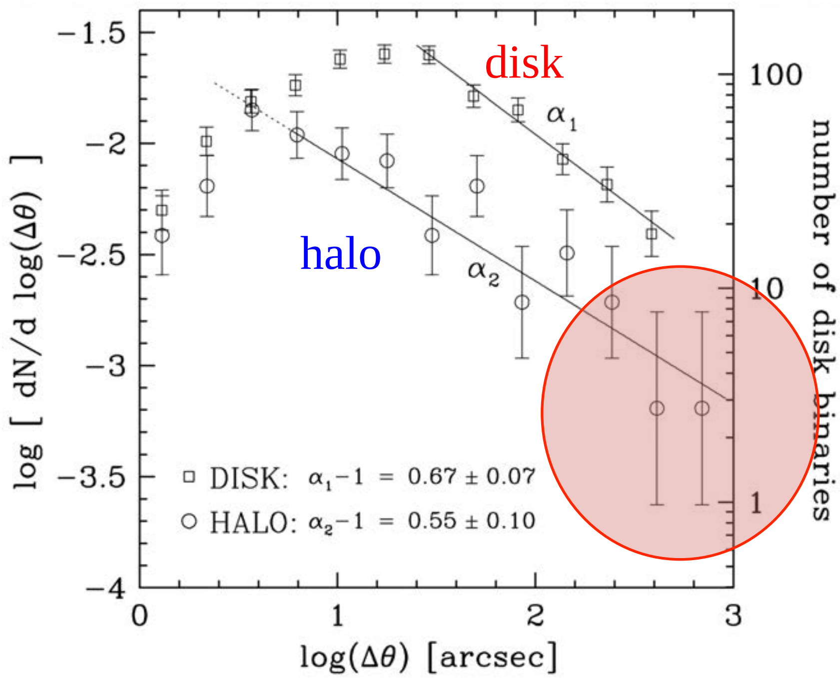

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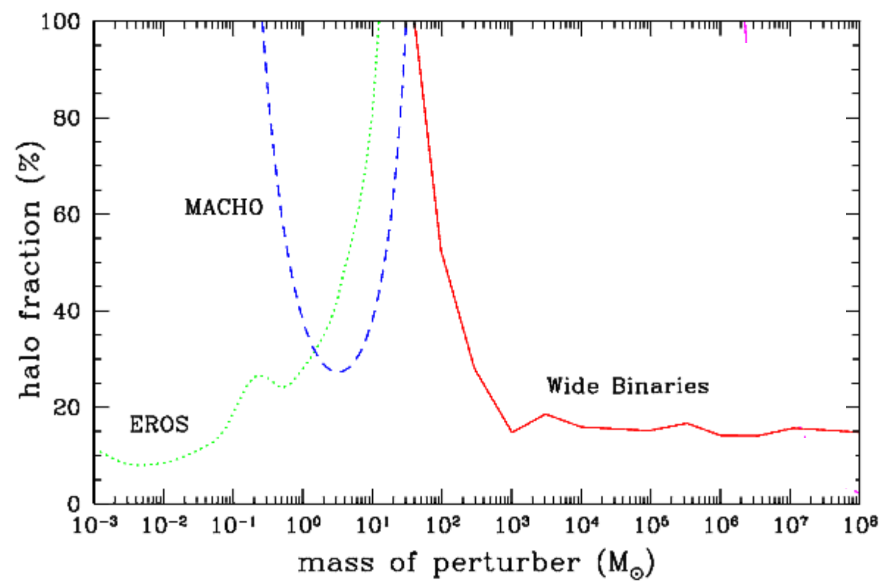

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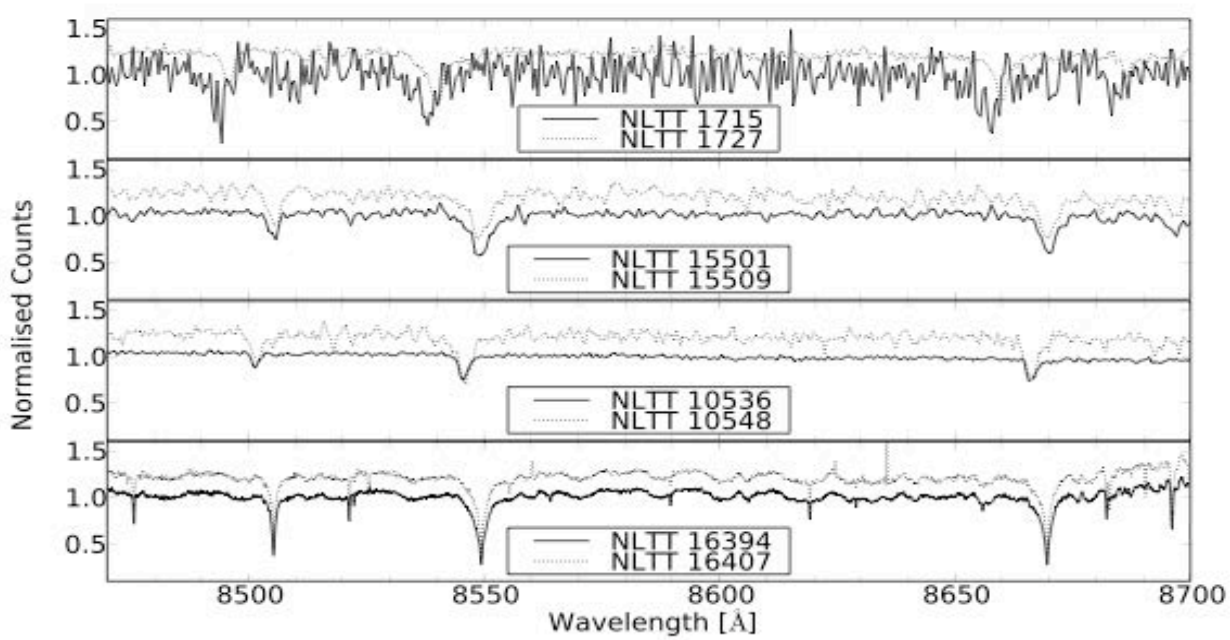
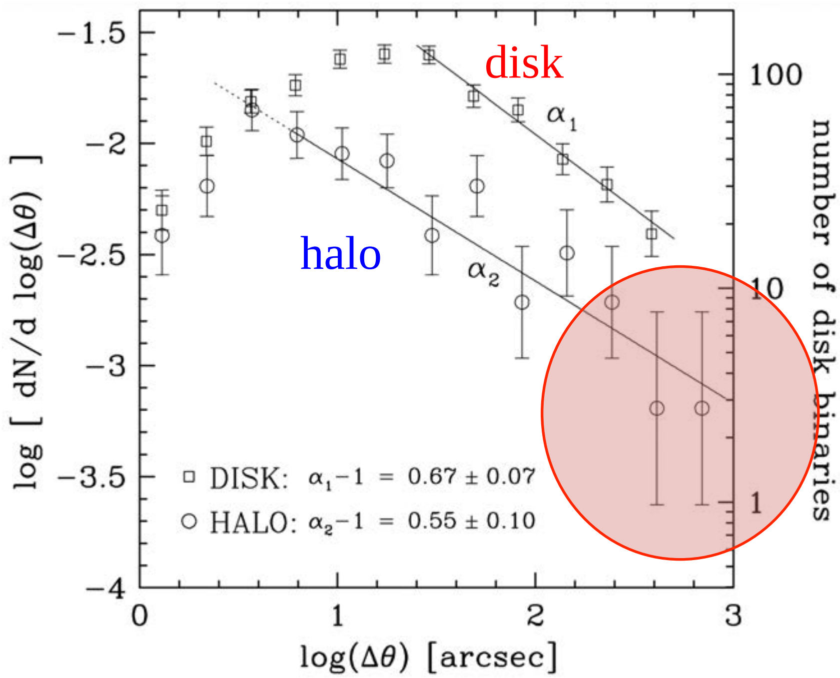


Figure 1. Spectra for the four candidate binary systems we have observed. The top three panels show data from our WHT observations, while the bottom panel shows the data for the pair NLTT 16394/16407 taken with the Magellan telescope. In each panel, the spectra are centred on the Ca II triplet region. The spectra for each member of a candidate binary are plotted together. The second component is shifted slightly upwards for clarity.

Constraining Halo Dark Matter



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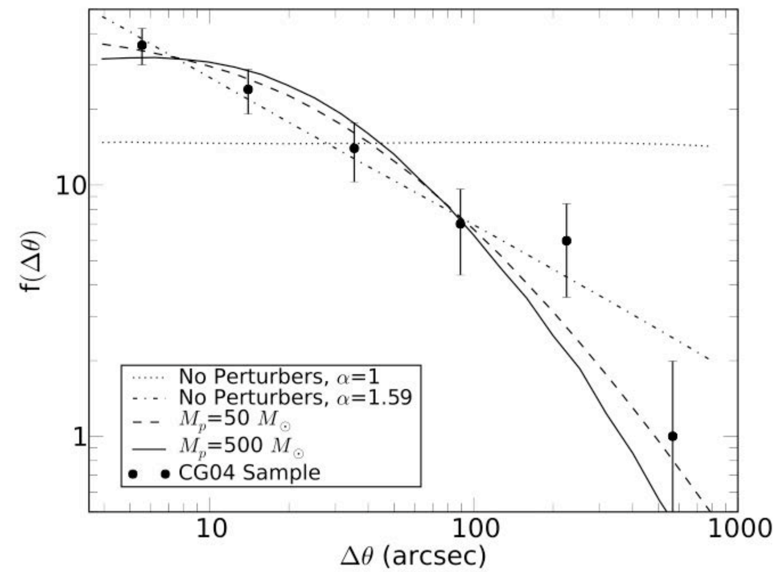

Figure 2. A comparison of the predicted observable angular separation function for a number of models. See text for details. The observed distribution, from the CG04 homogeneous sample less the spurious pair, is also shown with associated Poisson errors.

Constraining Halo Dark Matter

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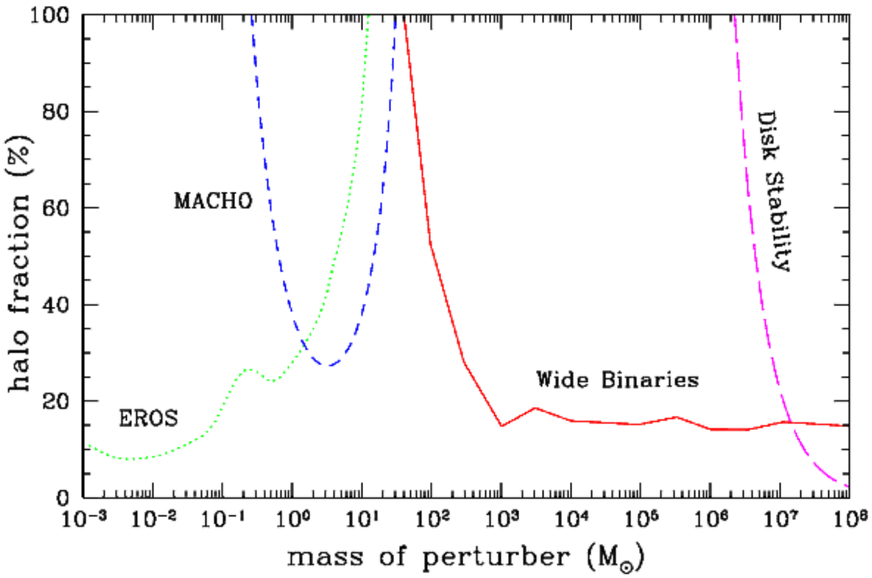

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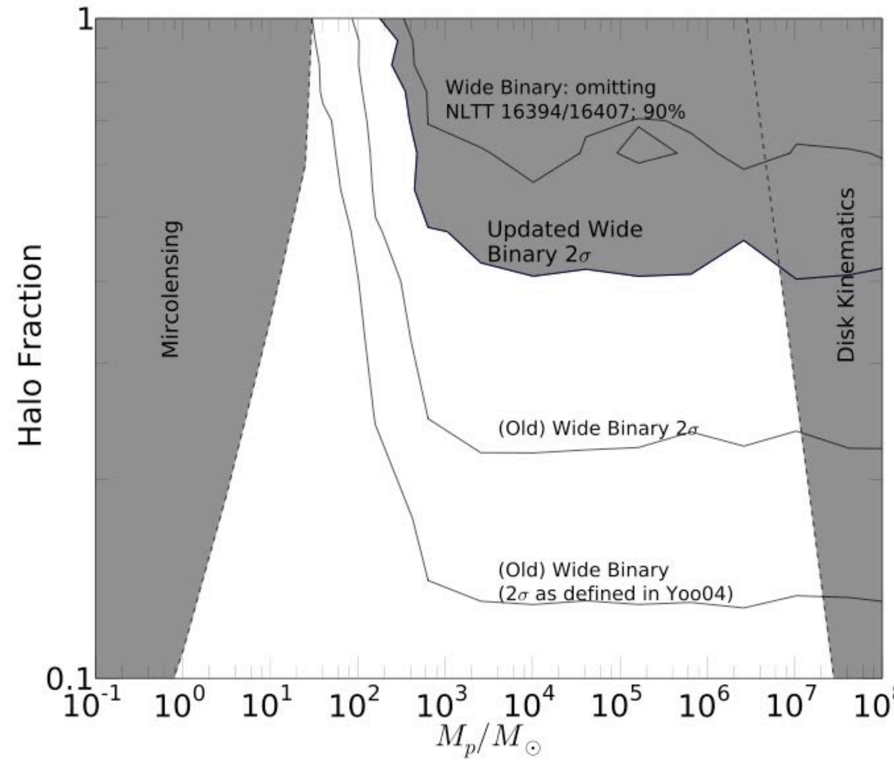


SDSS

+

USNO-B

Johanna Coronado & JC (2016, in prep)

DR9 + USNO-B

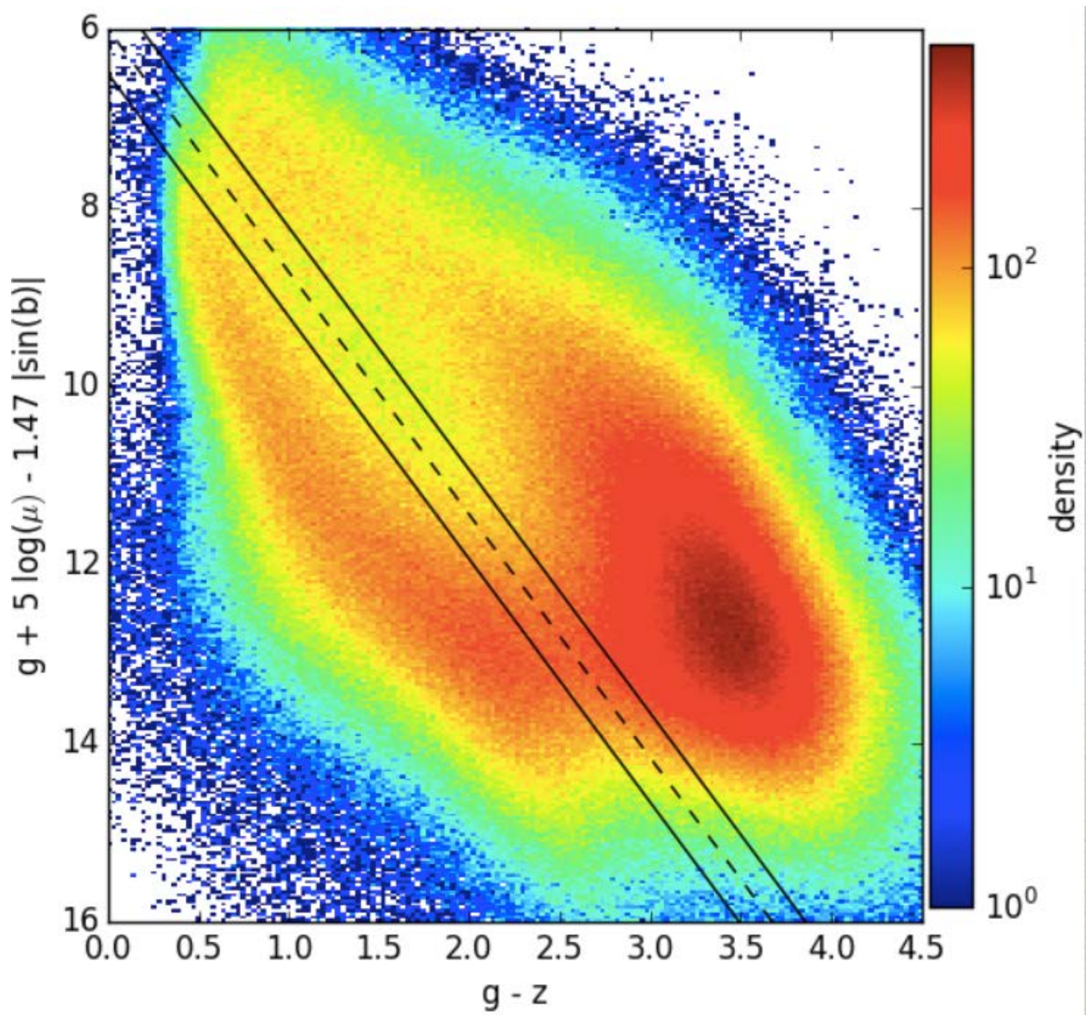
↓

~ 4 ×10^6 halo stars

r' < 18

μ > 20 mas/yr

$\sigma_\mu \approx$ 4 mas/yr



SDSS
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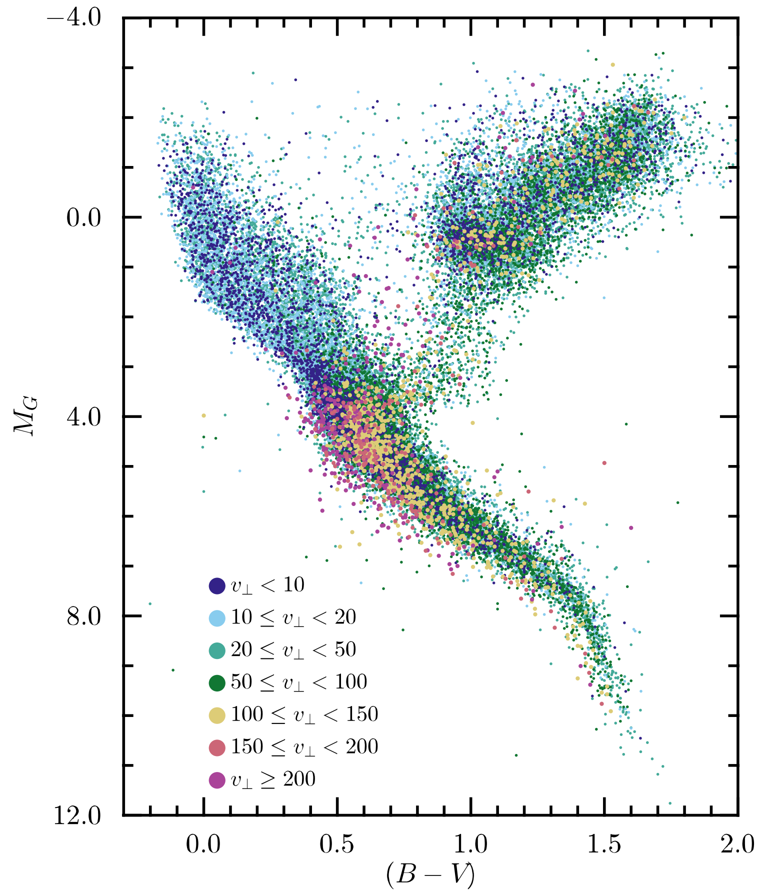
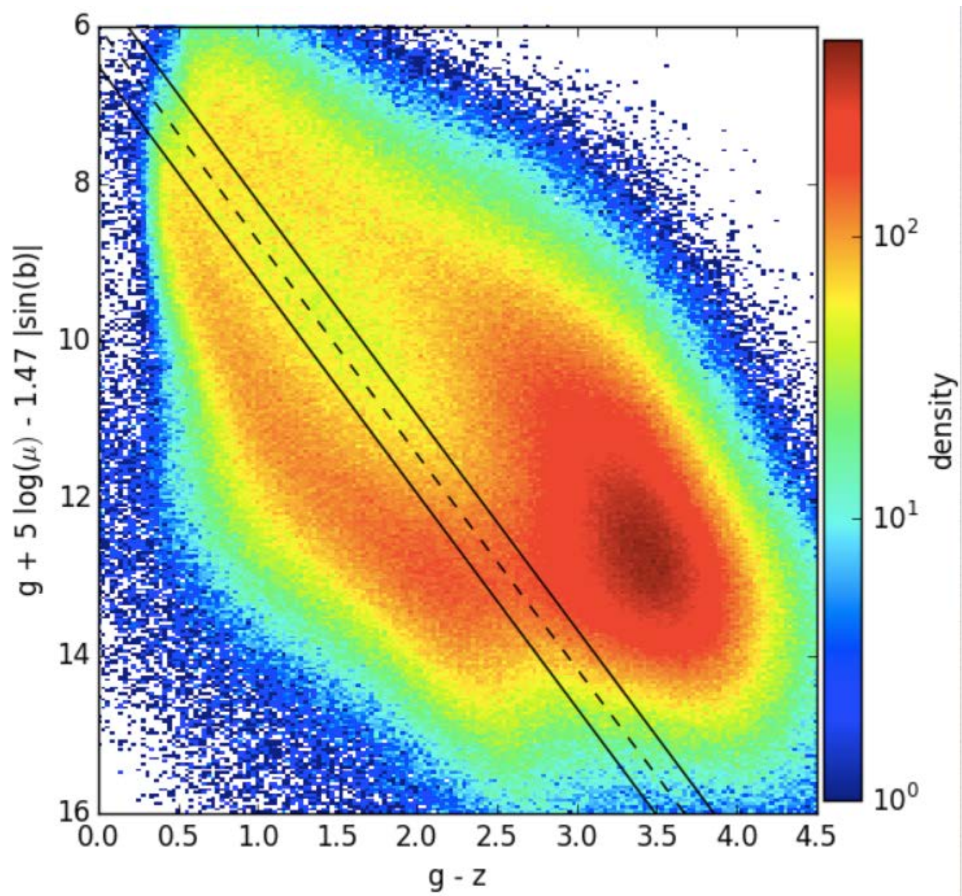




SDSS

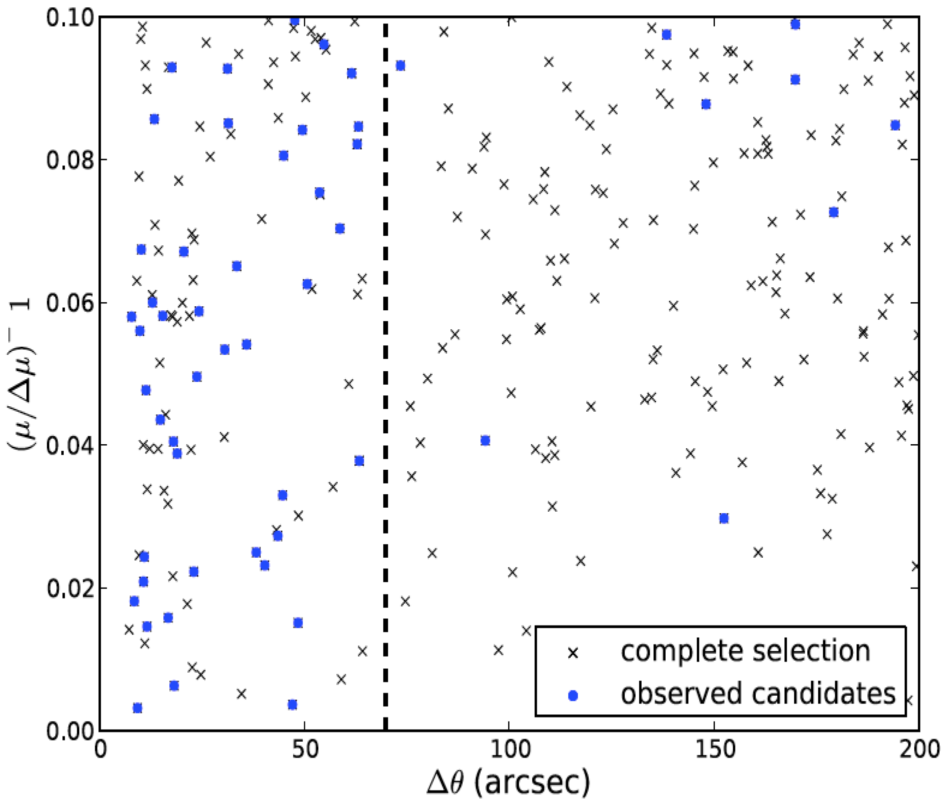
+

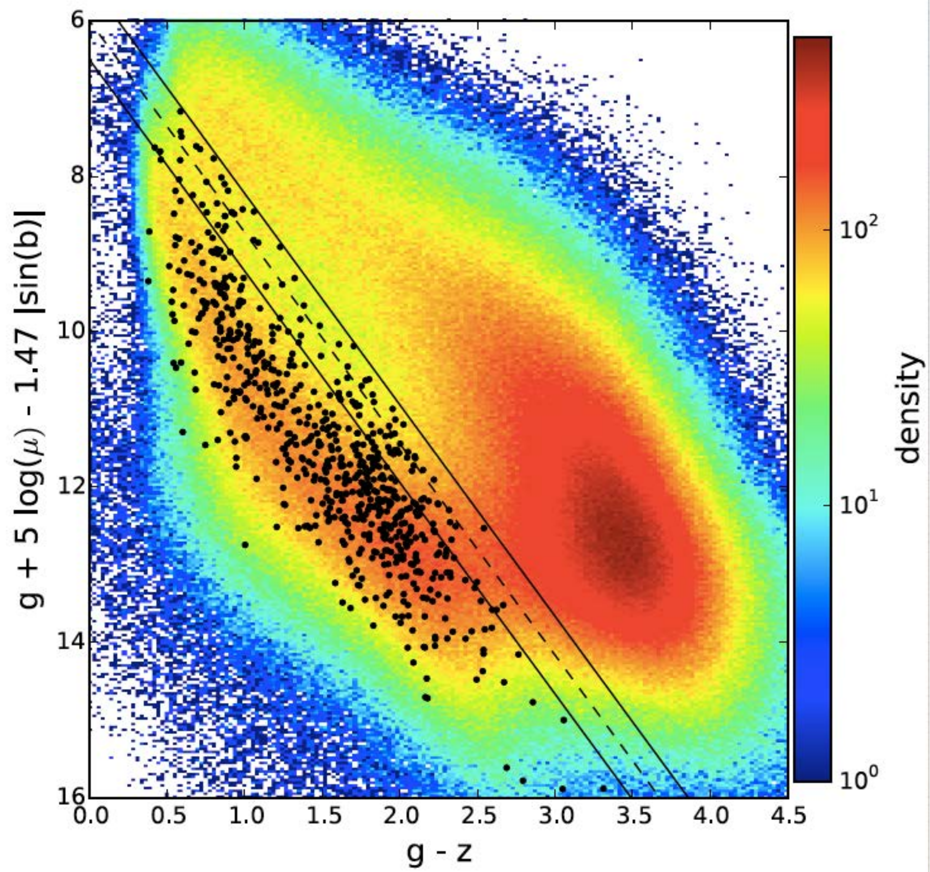
USNO-B

$$5'' < \Delta\theta < 200''$$

$$\Delta\mu = \sqrt{(\mu_{l1} - \mu_{l2})^2 + (\mu_{b1} - \mu_{b2})^2}$$

$$\mu/\Delta\mu > 10$$





SDSS

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USNO-B

Johanna Coronado & JC (2016, in prep)

Long slit spectra from:

KPNO: Mayall 4m and KOSMOS spectrograph 5600-9600 Å

R ~2200

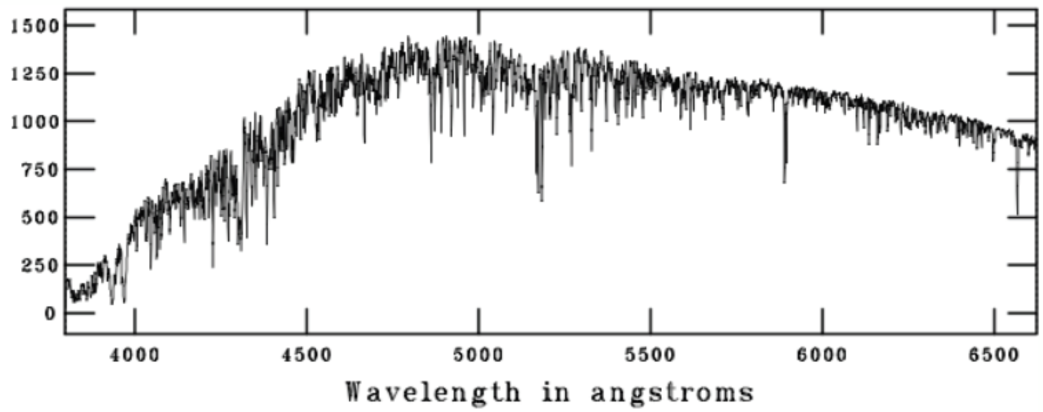
CTIO: Blanco 4m, COSMOS spectrograph 3800-6600 Å

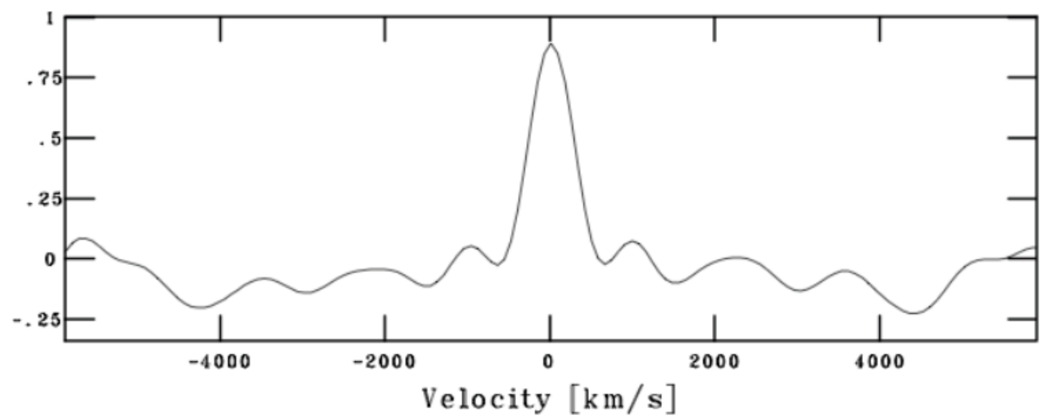
R ~2100

La Silla: NTT, EFOSC2 spectrograph 6047-7147 Å

R~3200

In total: 16 nights of observations and 89 candidate wide halo binaries observed





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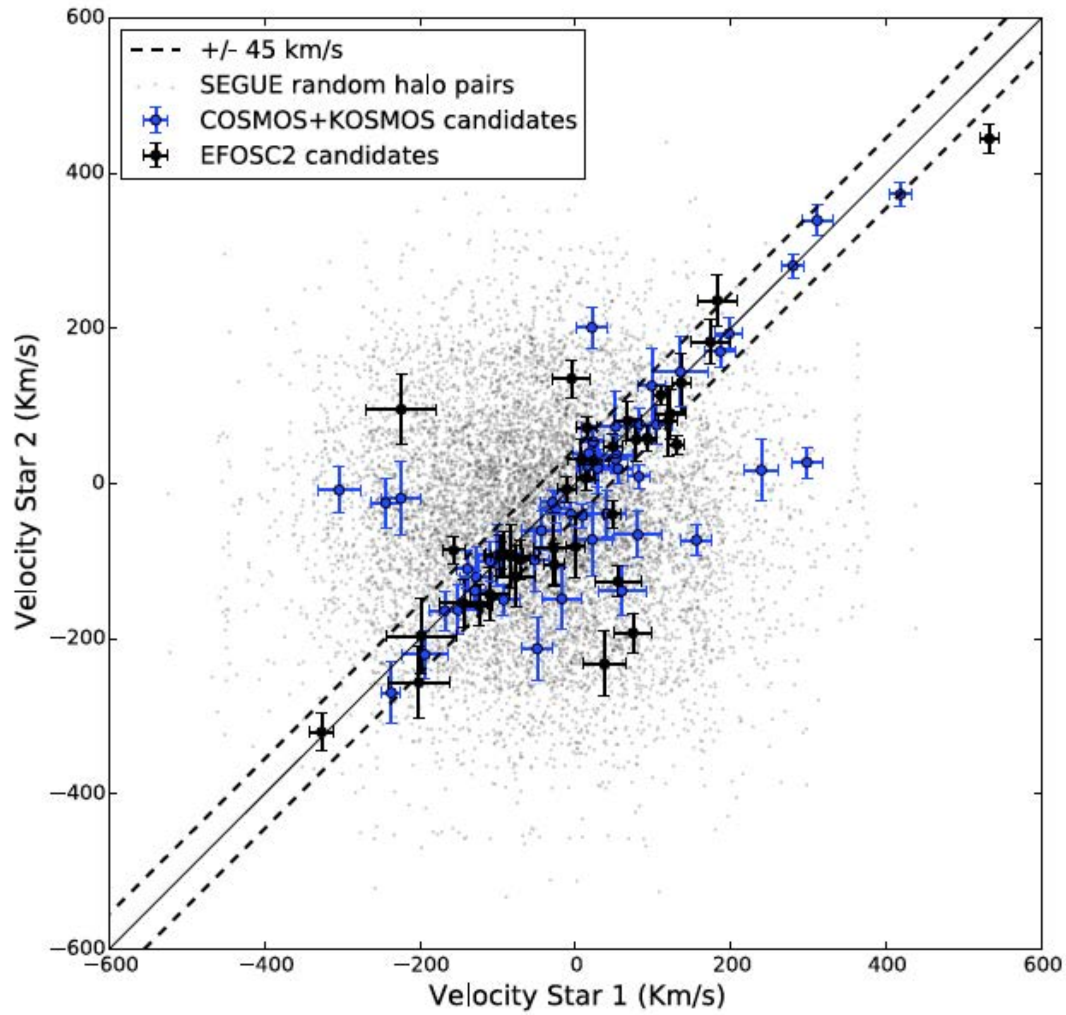

SDSS

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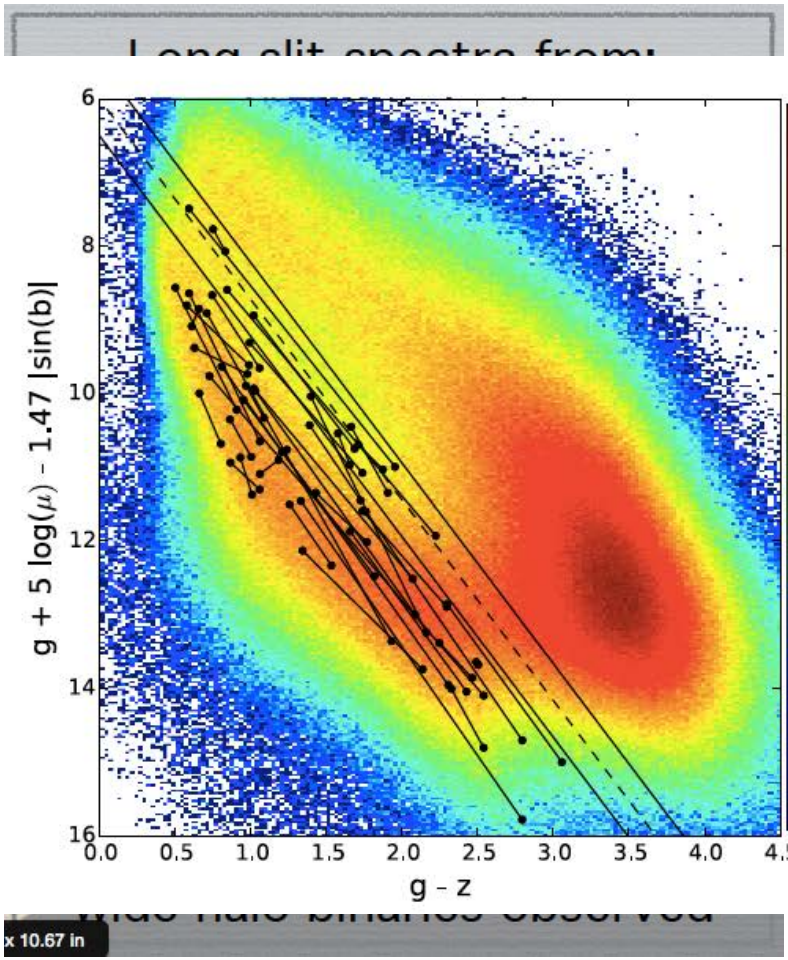

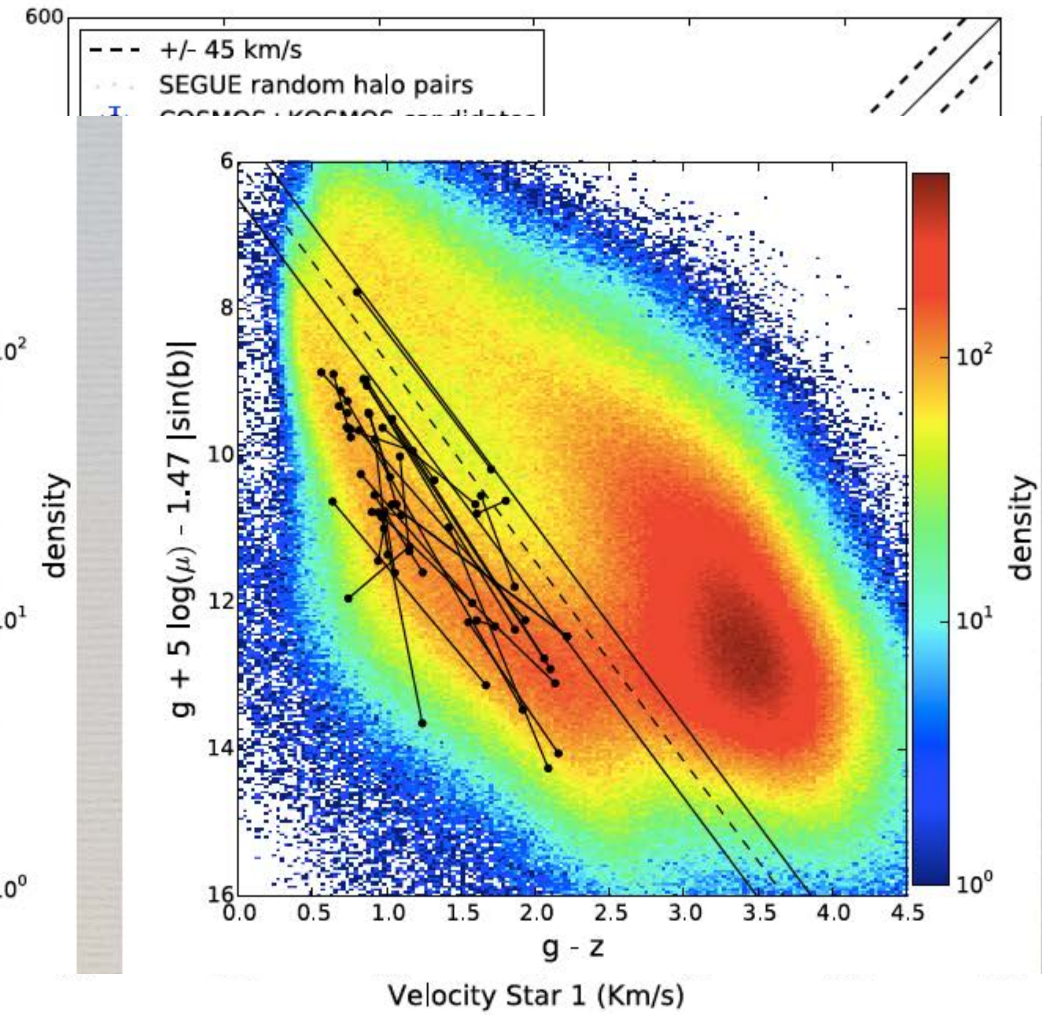

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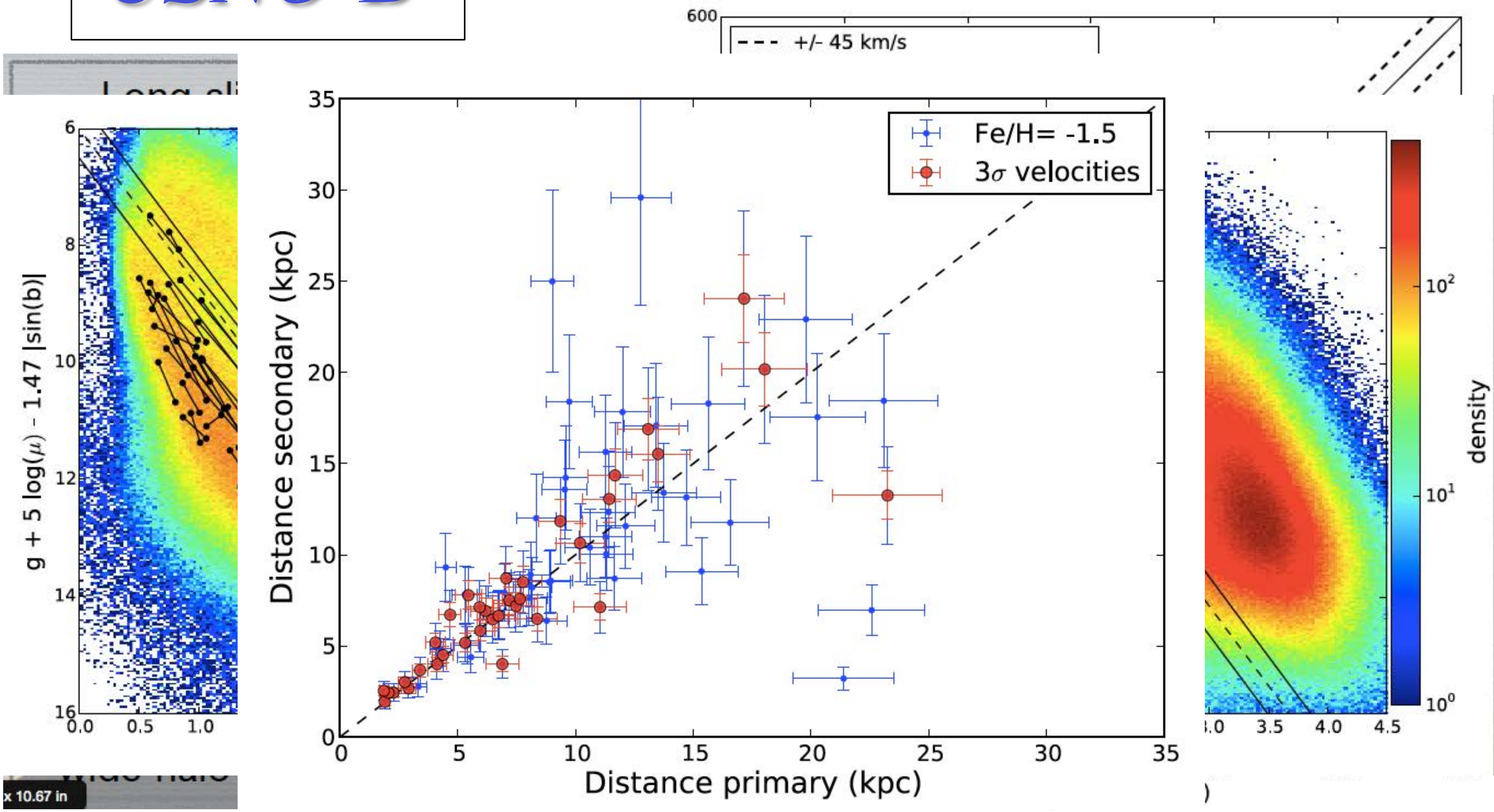


Concluding remarks

- Search of halo wide binary candidates in SDSS through common proper motion criteria
- Proper motion alone already selects many genuine halo wide binaries, roughly 55% of the sample is composed of true bounded systems
- The calculated photometric distances of the candidate halo wide binaries show that these are several kilo-parsecs away, having candidates up to 25 kpc.
- A contamination analysis showed that most of the contamination is present at low proper motions and increases at fainter magnitudes
- A stronger criterion in proper motion will allow a much higher rate of success in finding genuine binaries from the candidate pairs and to apply it with no need of RV measurements
- This new assembled catalog will help in the future goal of statistically select larger samples from the entire SDSS , or Gaia for example

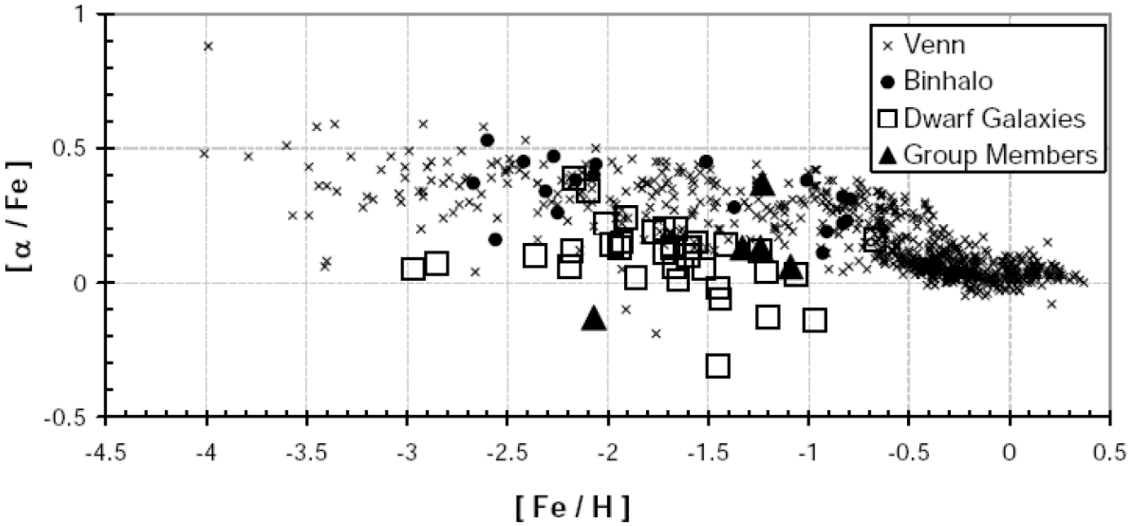
The End

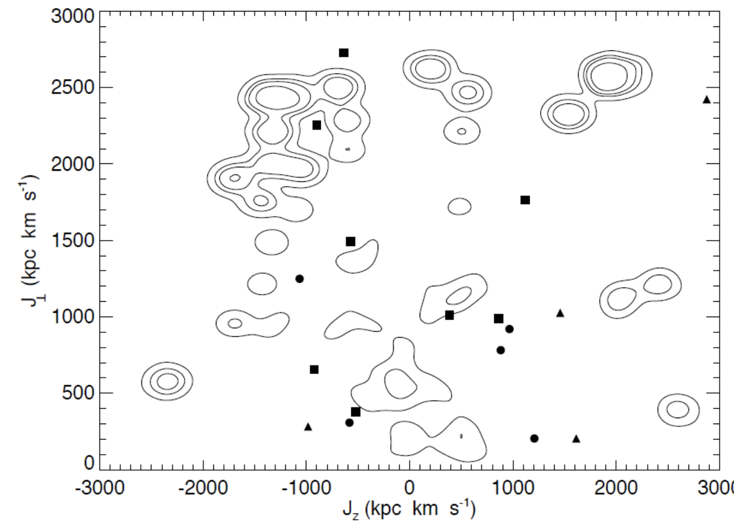
Constraining Halo Dark Matter

- more sophisticated modeling
- understanding the *genesis* of halo wide binaries
- larger samples of halo binaries

María Paz Sepúlveda & JC (2017, in prep)

Quinn & Smith (2009)





■ ● ▲ binaries

Allen, Poveda, & Hernández-Alcántara (2007)

Constraining Halo Dark Matter

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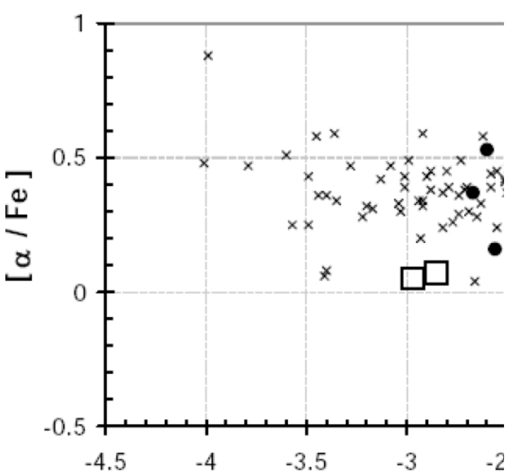
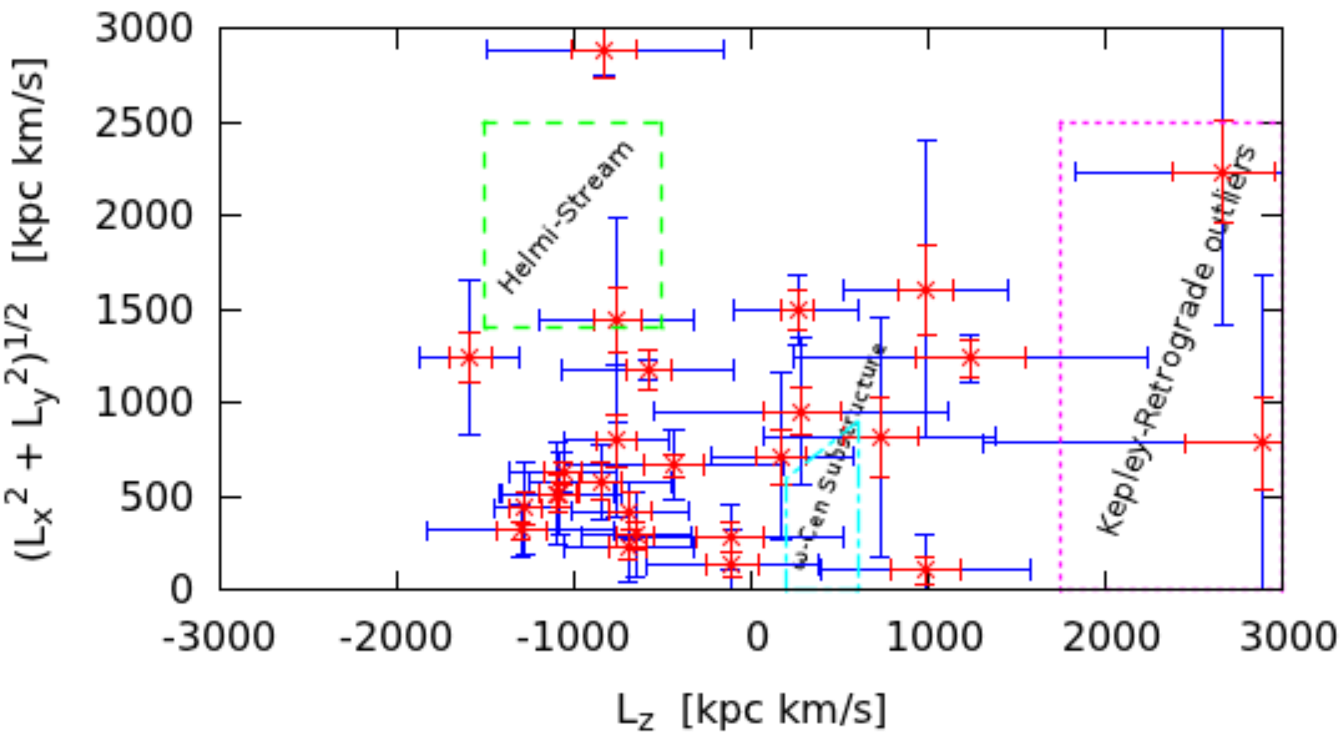


Allen, Poveda, & Hernán



Formation of wide binaries

- clustered star formation?
- dynamical capture in the field?

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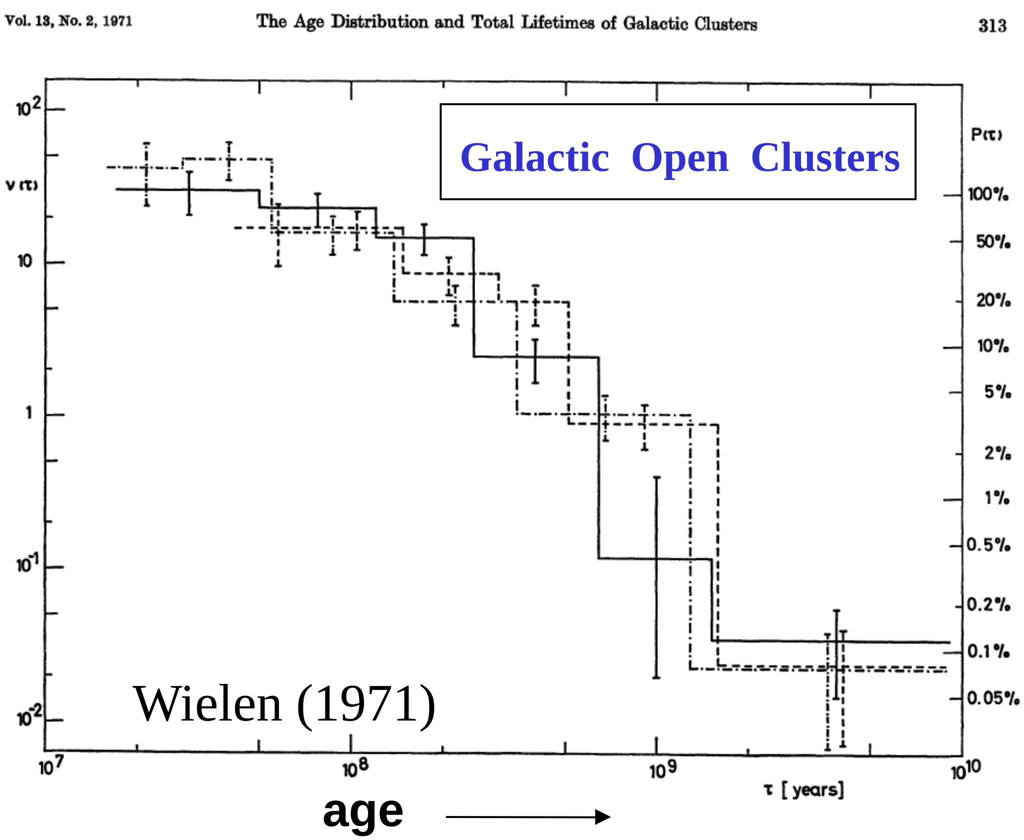


open clusters are destroyed by giant molecular clouds

(Binney & Tremaine, Sec.7.2)

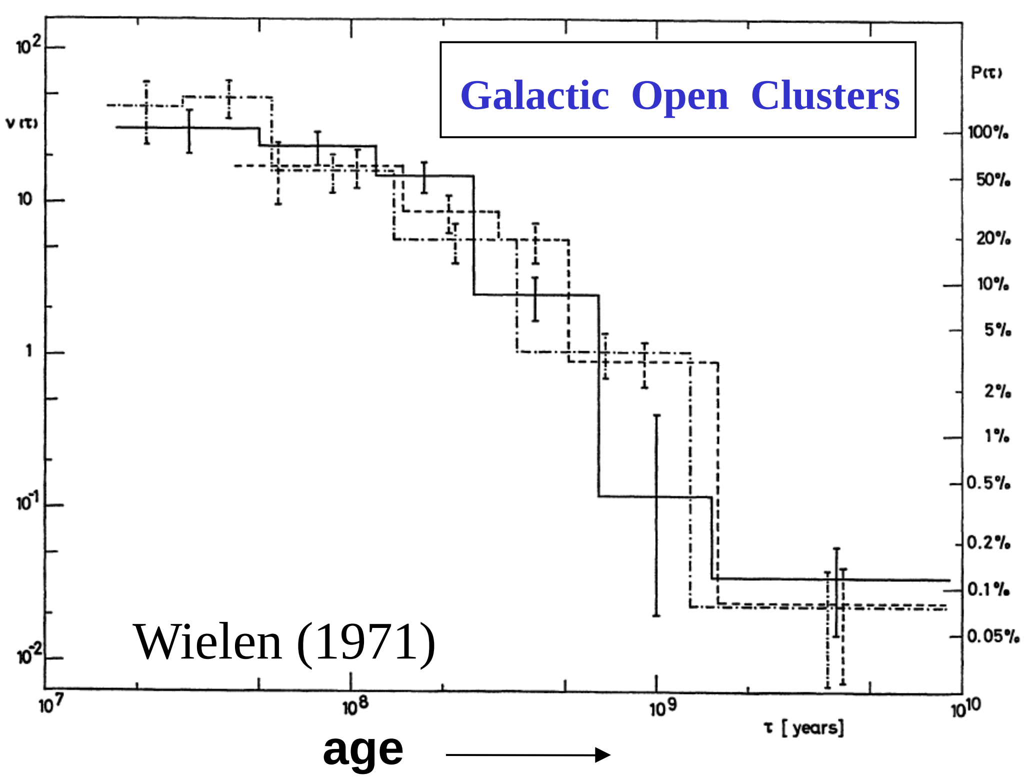
Formation of wide binaries

- clustered star formation?
- dynamical capture in the field?

formation during the dissolution phase of star clusters

Kouwenhoven et al. (2010)

Vol. 13, No. 2, 1971 The Age Distribution and Total Lifetimes of Galactic Clusters 313



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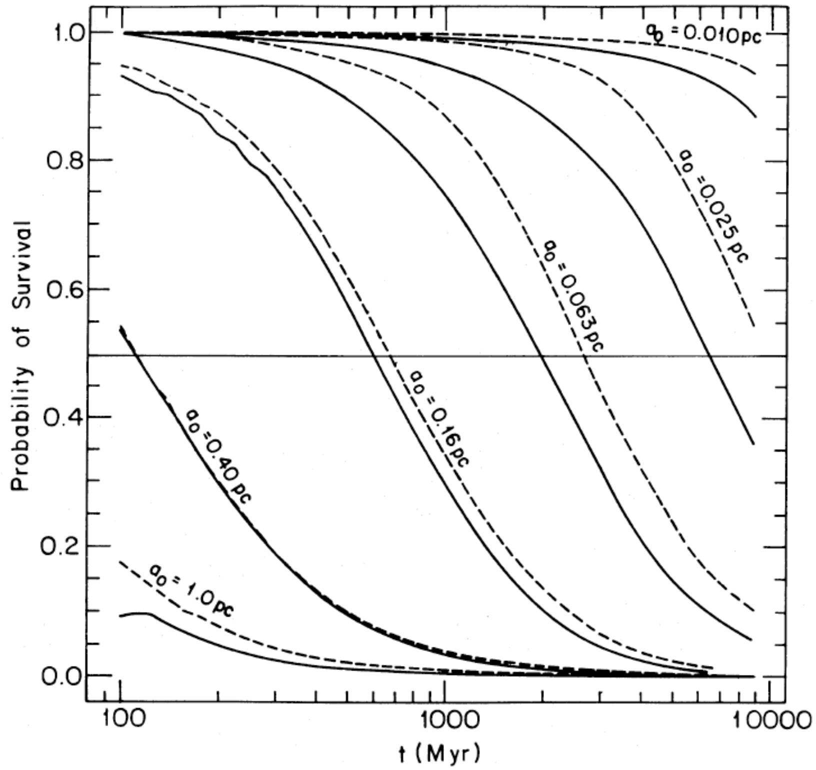
Today's distribution of semi-major axes

effect of giant molecular clouds



Weinberg, Shapiro, & Wasserman (1987)
Wasserman & Weinberg (1991)
Jiang & Tremaine (2009)

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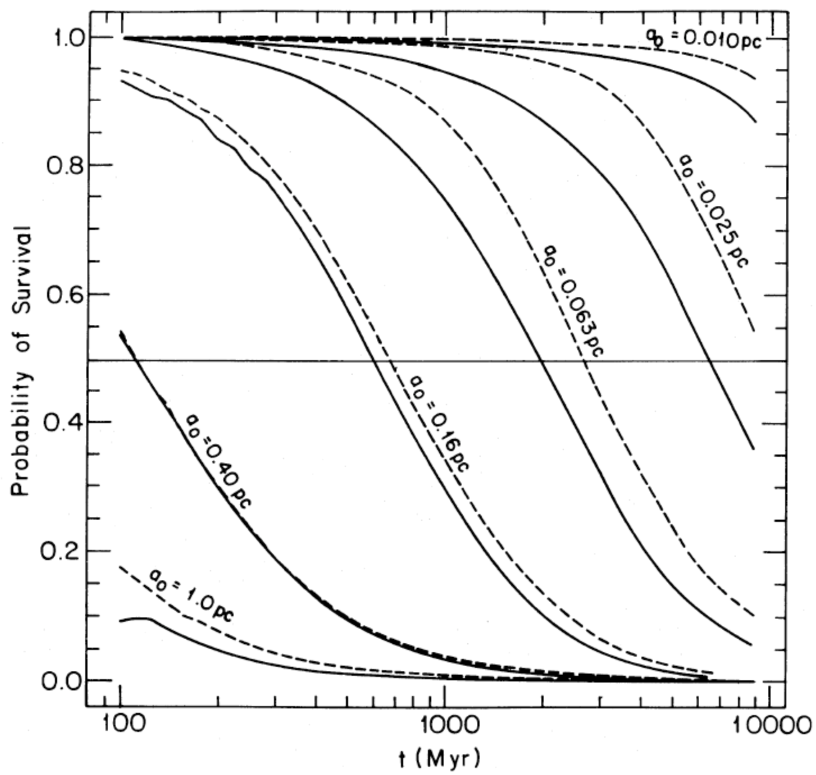

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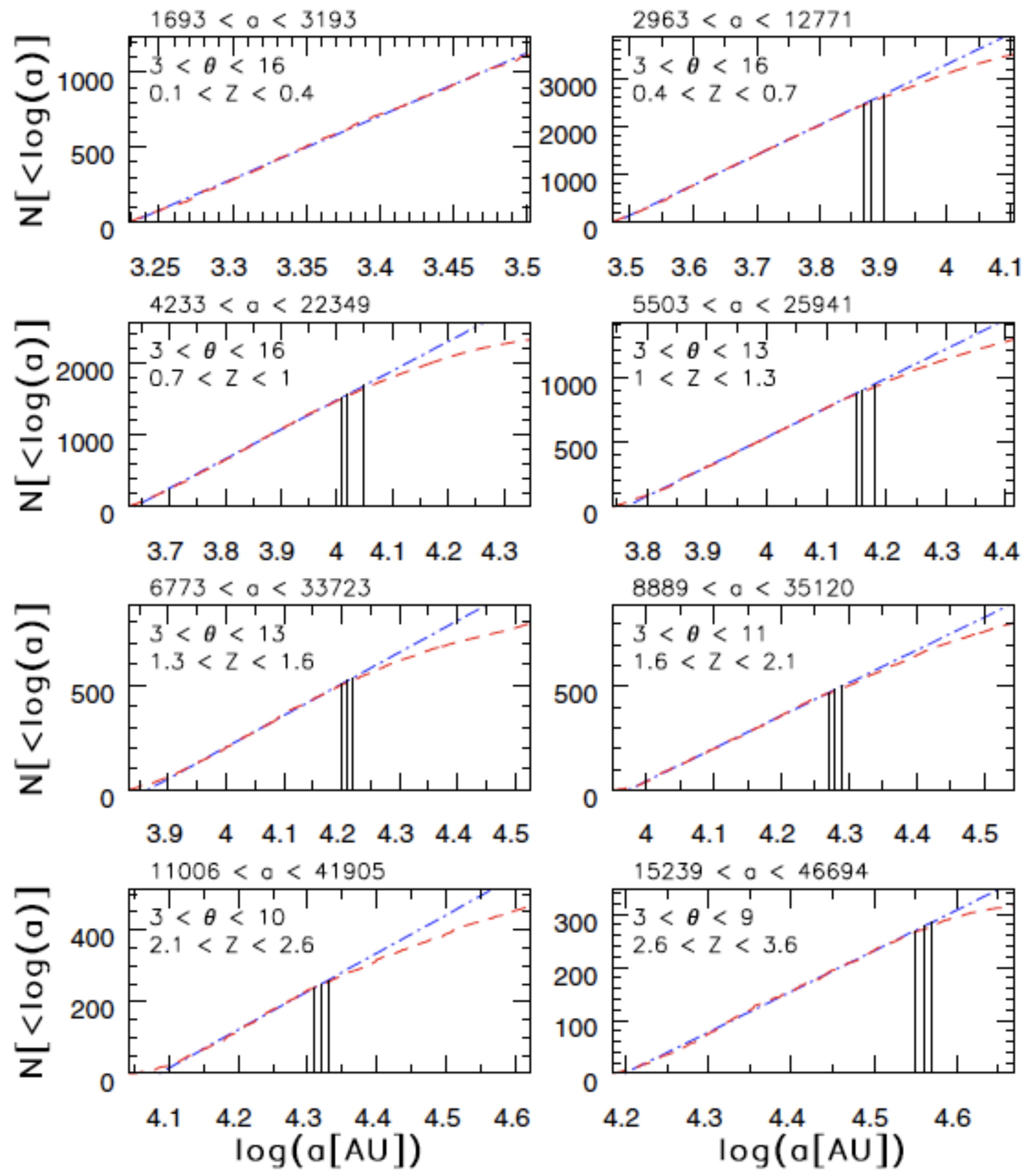
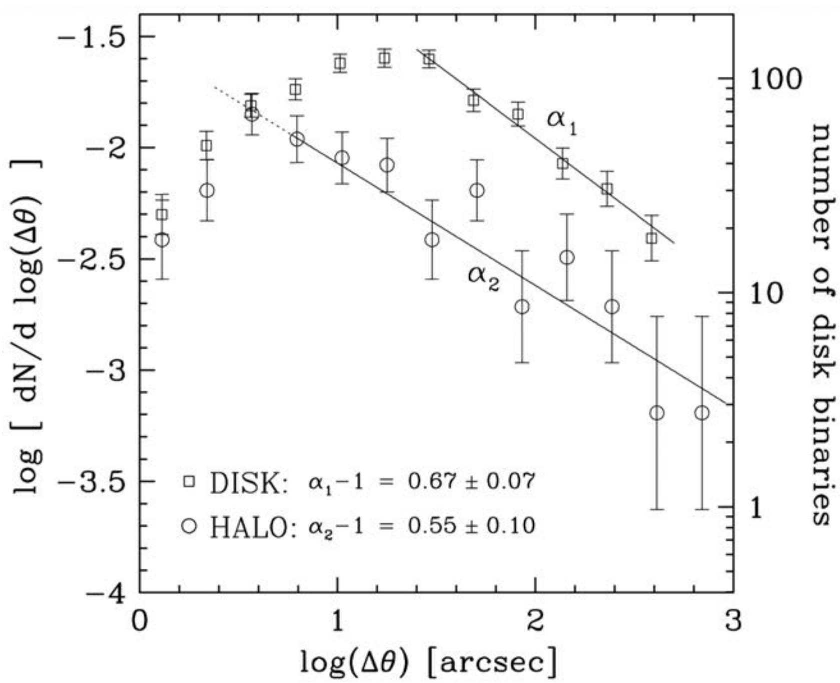
SDSS disk binaries!!



Sesar, Ivezić, & Jurić (2008)

… we have systems much wider than 0.1 pc !!!

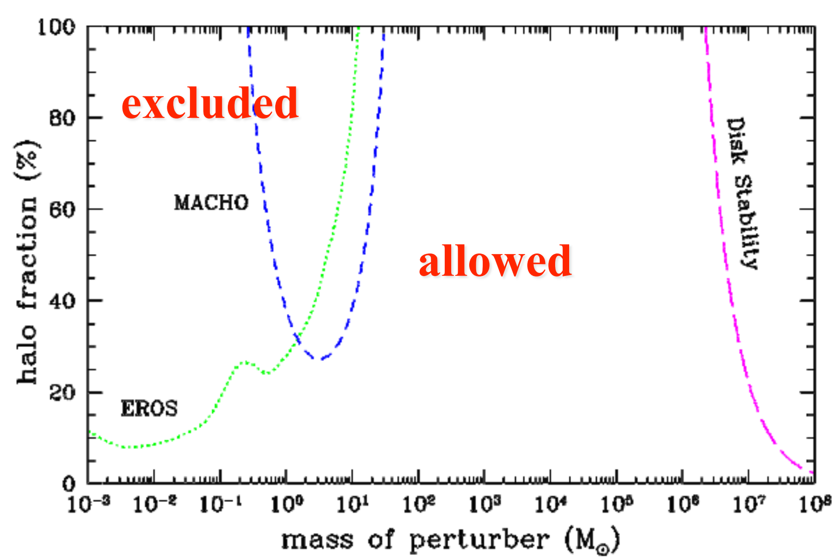
JC & Gould (2004)



0.1 pc

$$b_{min} \geq a_t$$

$$M \geq 10^3\ M_{\odot}$$



Since binaries with large semimajor axes, a ≥ 0.1 pc, are more easily disrupted than those with small ones, any deviation (or lack thereof) from a power-law distribution at wide separations provides a test of halo dark matter models.

Constraining Halo Dark Matter

Monte Carlo Simulations

- simple impulse approximation
- no disk or Galactic tides
- constant density of perturbers

- combinations of (M,ρ) of MACHOs

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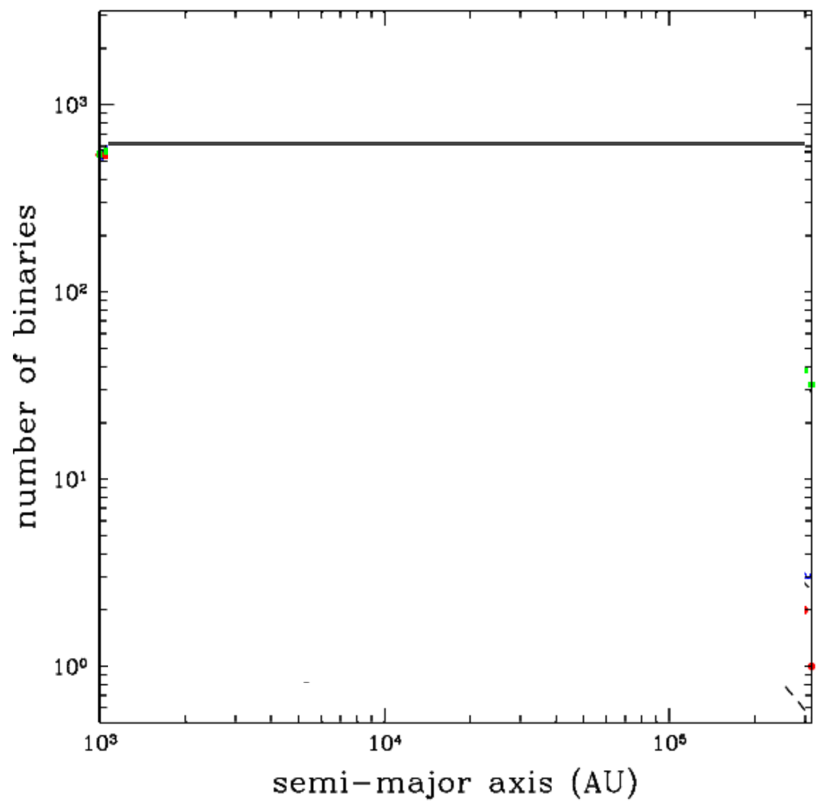

Yoo, Chanamé, & Gould (2004)

$$b_{\min} = \left(\frac{M}{\pi \rho v T}\right)^{1/2} = 700\ \mathrm{AU} \left(\frac{M}{\mathrm{M}_\odot}\right)^{1/2} \left(\frac{\rho}{\rho_H}\right)^{-1/2} \left(\frac{v}{300\ \mathrm{km\ s^{-1}}}\right)^{-1/2}$$

b_{min} >> a ⇒ "tidal limit"

closest encounter is the most important one

$$\Delta v \simeq \frac{2GM}{b^2 v} a.$$

$$a_t = \left(\frac{m}{4\pi^2 G \rho^2 T^2}\right)^{1/3} \simeq 18{,}000\ \mathrm{AU} \left(\frac{\rho}{\rho_H}\right)^{-2/3}$$

b_{min} << a ⇒ "Coulomb limit"

all encounters are equally important

$$(\Delta v)^2 = 2 \int_{b_{\min}}^{a} 2\pi b\, db \left(\frac{2GM}{bv}\right)^2 \frac{\rho}{M} vT = \frac{16\pi G^2 \rho M T}{v} \ln \Lambda$$

$$a_t = \frac{mv}{16\pi G \rho M T \ln \Lambda} = \frac{3000\ \mathrm{AU}}{\ln \Lambda} \left(\frac{M}{10^3\ \mathrm{M}_\odot}\right)^{-1} \left(\frac{\rho}{\rho_H}\right)^{-1}$$

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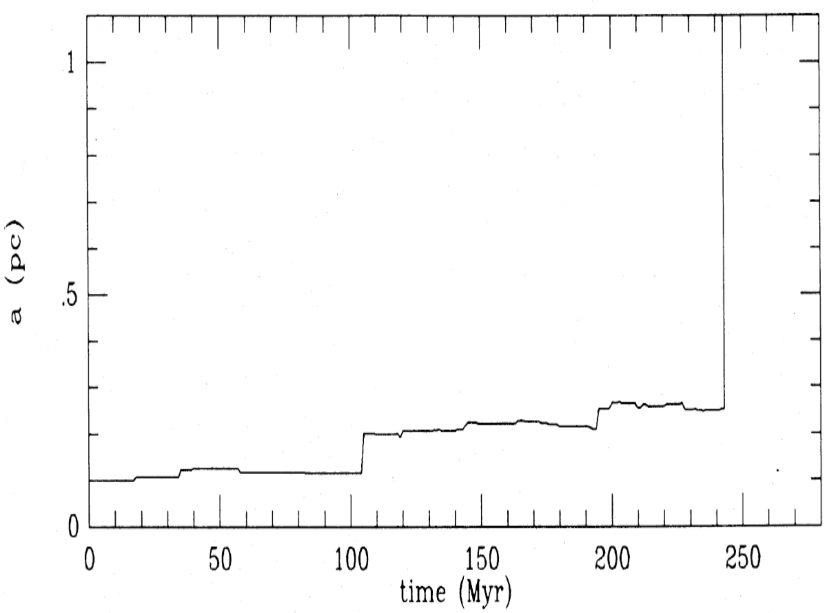

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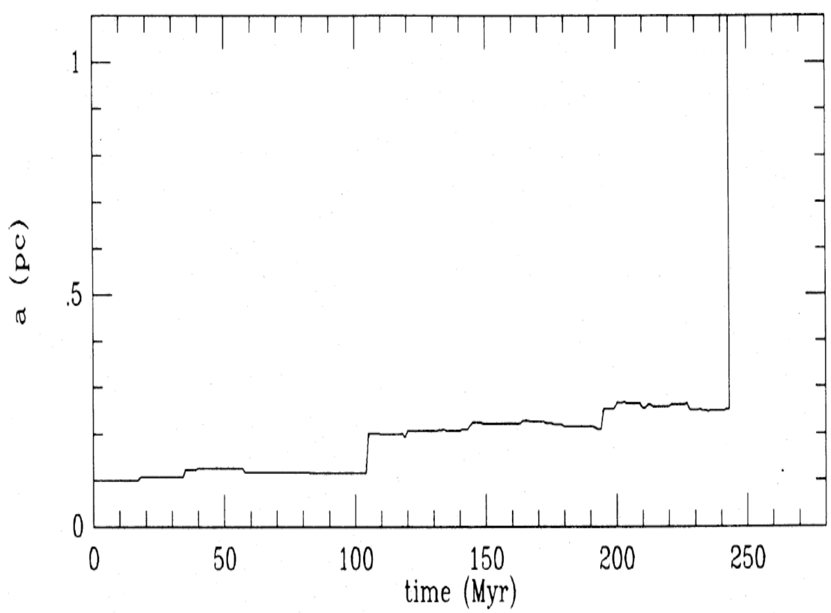

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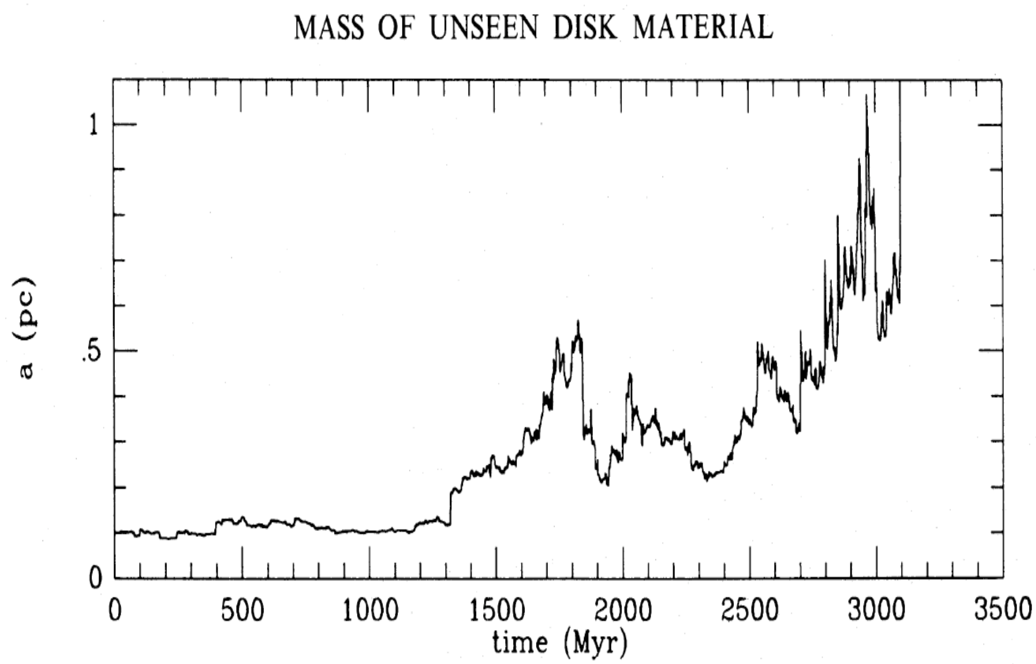

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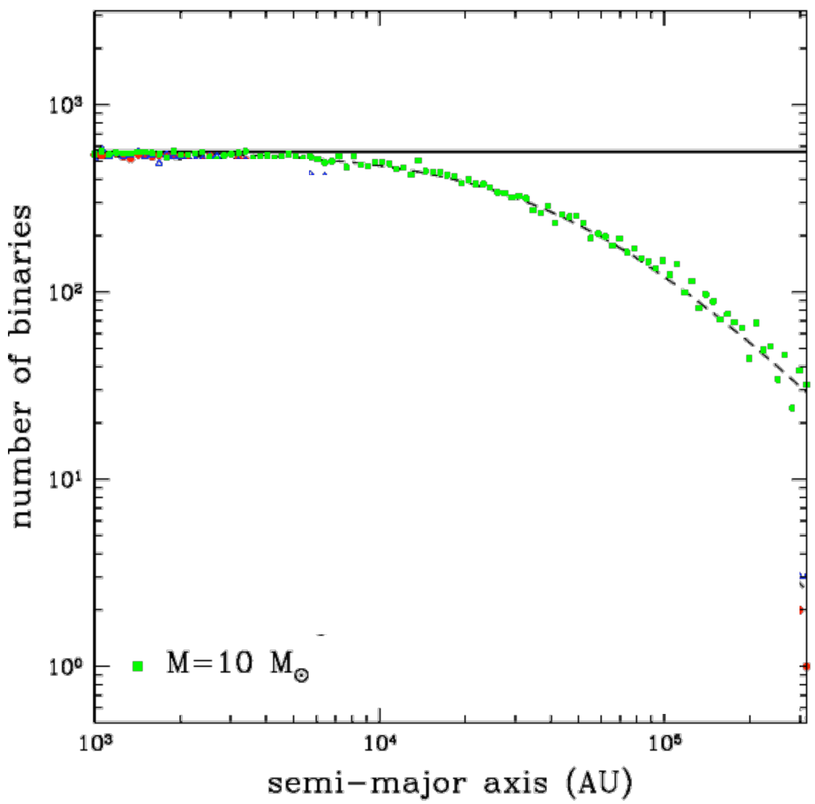

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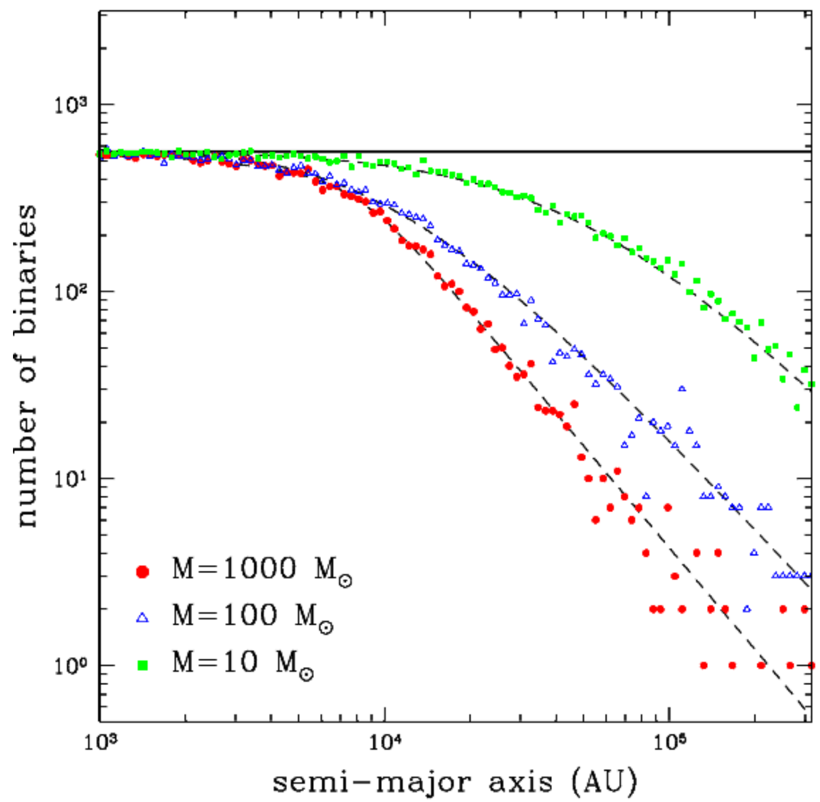

Yoo, Chanamé, & Gould (2004)

Galactic Stellar Populations and Dynamics

Julio Chanamé

Populations of Wide Binaries and Applications

- halo dark matter probes (Johanna Coronado, María Paz Sepúlveda)
- Initial-to-final mass relation for white dwarfs – mass loss constraints (Carol Rojas)
- precise, systematic ages of old field stars – gyrochronology (Diego Godoy)
- genesis/assembly of halo wide binary population (María Paz Sepúlveda)
- formation during cluster dissolution (César Guerra, PUC Perú)

Stellar Evolution / Stellar Rotation and Activity

- fast rotation and Li enrichment among RGB stars (Claudia Aguilera)
- Li, activity, rotation, and the presence of planets (Carol Rojas, Claudia Aguilera)

Stellar Dynamics + Milky Way Substructure and Assembly

- dynamical modelling of dwarf galaxies – dark matter content (Francisco Aros)
- stellar halo assembly – globular cluster debris in the Galactic field (Camila Navarrete)
- stellar counterpart of gaseous Magellanic Stream (Roberto Muñoz, Camila Navarrete)
- evolution of dwarf galaxies in galaxy clusters (Marcelo Mora, Thomas Puzia)